

## **Summary of Expansions and Revisions in GREET1.8d Version**

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July 30, 2010

This release of the GREET model includes the following major updates:

1. Updated overall petroleum refinery efficiency on the basis of 2008 petroleum refinery data from the Energy Information Administration's (EIA's) annual survey and revised allocation of refinery energy use among the different fuel products
2. Updated corn ethanol pathway with revised farming energy use on the basis of (a) newly available U.S. Department of Agriculture data; (b) ethanol plant energy use, which is based on an ethanol plant survey by University of Illinois at Chicago; and (c) animal feed displacement ratios, which are based on an updated Argonne analysis; as part of update, GREET now includes options for domestic and foreign land-use change associated with corn-ethanol production based on simulations by Purdue University with its Global Trade Analysis Project (GTAP) model
3. Updated cellulosic ethanol pathways with revised farming requirements and plant design (the latter is based on data that the National Renewable Energy Laboratory developed recently)
4. Updated soybean-based biodiesel pathway with revised farming and biodiesel conversion estimates from two recent studies
5. Updated gas-to-liquids (GTL), coal-to-liquids (CTL), biomass-to-liquids (BTL), and coal and biomass to liquids (C/BTL) pathways with additional design options and updated efficiency and co-product yields from a completed Argonne study
6. Added new pathways for landfill gas (LFG) to produce compressed natural gas (CNG) and liquefied natural gas (LNG) from a completed Argonne study
7. Updated (a) fuel economy of baseline vehicle on the basis of the most recent EIA and U.S. Environmental Protection Agency (EPA) publications and (b) fuel economies of alternative vehicle technologies on the basis of updated simulations with Argonne's PSAT model
8. Updated projections of U.S., California (CA), and northeastern (NE) electricity generation mixes on the basis of EIA's Annual Energy Outlook 2010 and expanded renewable electricity generation to include solar, wind, hydro, and geothermal power generation technologies

9. Added options to account for energy uses and emissions associated with the construction of infrastructure for various electric power plants on the basis of an ongoing Argonne study
10. Updated pathways for plug-in hybrid electric vehicles (PHEVs) and battery-powered electric vehicles (BEVs) on the basis of revised electricity consumption in charge-depletion (CD) mode and driving range of electric vehicles and included estimates for two different PHEV designs (power-split design and series design), all of which are based on a completed Argonne study
11. Updated and revised several transportation and distribution activities and parameters

Details of the major updates and data sources and references are presented below.

- a. Updated overall petroleum refinery efficiency and revised allocation of refinery energy use among the different fuel products(Reference: Ignasi Palou-Rivera and Michael Wang, 2010, “Updated Estimation of Energy Efficiencies of U.S. Petroleum Refineries,” Center for Transportation Research, Argonne National Laboratory, Available at: <http://www.transportation.anl.gov/pdfs/TA/635.PDF>)
  - b. Updated petroleum refinery process fuel use on the basis of EIA Refinery Capacity Report 2009 on fuel consumed at refineries by Petroleum Administration for Defense (PAD) districts in 2008
  - c. Updated merchant and captive hydrogen consumption at refineries on the basis of 2006 data found in The Chemical Economics Handbook, 743.5002
  - d. Revised refinery energy-intensity ratios for gasoline, diesel, LPG, naphtha, and residual oil to reflect actual energy use and emissions for each fuel product and hydrogen-producing and -consuming sources within a refinery. This revision was based largely on Larry Bredeson, Raul Quiceno, Xavier Riera-Palou, and Andrew Harrison, 2010 (“Factors Driving Refinery CO<sub>2</sub> Intensity, with Allocation into Products,” *The International Journal of Life Cycle Assessment*, DOI 10.1007/s11367-010-0204-3)
2. Updated corn ethanol pathway with revised farming energy use, ethanol plant energy use and animal feed displacement ratios and included options for domestic and foreign land-use change associated with corn-ethanol production:
  - a. Updated corn farming assumptions on the basis of a USDA report (Reference: Shapouri, H., P.W. Gallagher, W. Nefstead, R. Schwartz, S. Noe, and R. Conway, 2010, “2008 Energy Balance for the Corn-Ethanol Industry,” Agricultural Economic Report Number 846)

- b. Updated dry mill corn ethanol plant assumptions on the basis of data in EPA's final rule of renewable fuels standards and the Survey on Ethanol Plants by University of Illinois at Chicago (UIC) (References: [1] U.S. EPA, 2010, "Renewable Fuel Standard Program [RFS2] Regulatory Impact Analysis," EPA-420-R-10-006, and [2] Mueller, S., 2010, "2008 National Dry Mill Corn Ethanol Survey," *Biotechnology Letters*, DOI 10.1007/s10529-010-0296-7)
  - c. Updated wet mill corn ethanol plant assumptions on the basis of the Renewable Fuels Association's survey on ethanol plants (Reference: Wu, M., 2008, "Analysis of the Efficiency of the U.S. Ethanol Industry 2007")
  - d. Included options for calculating domestic and foreign land-use change (LUC) for corn-ethanol pathway on the basis of Purdue's GTAP model simulations (Reference: Tyner, W.E., F. Taheripour, Q. Zhuang, D. Birur, and U. Baldos, 2010, "Land Use Changes and Consequent CO<sub>2</sub> Emissions due to US Corn Ethanol Production: A Comprehensive Analysis," Purdue University, Available at: <http://www.transportation.anl.gov/pdfs/MC/625.PDF>)
  - e. Included a LUC calculation tool (CCLUB) developed at Argonne (LUC calculation tool is a separate Excel file accessible through an internal link from within GREET and can be accessed externally at the GREET installation folder)
- 3. Updated Cellulosic ethanol pathways with revised farming requirements and plant designs; the latter update was based on recent NREL techno-economic simulations of cellulosic ethanol plants
- 4. Updated soybean-based biodiesel with revised farming and biodiesel conversion estimates:
  - a. Updated soybean farming assumptions on the basis of a USDA report (Pradhan, A., D.S. Shrestha, A. McAloon, W. Yee, M. Haas, J.A. Duffield, and H. Shapouri, 2009, "Energy Life-Cycle Assessment of Soybean Biodiesel," Agricultural Economic Report Number 845)
  - b. Updated biodiesel production assumptions on the basis of EPA's final rule of renewable fuels standards and a recent study ([1] U.S. EPA, 2010, "Renewable Fuel Standard Program [RFS2] Regulatory Impact Analysis," EPA-420-R-10-006, and [2] Omni Tech International, "Life Cycle Impact of Soybean Production and Soy Industrial Products," prepared for the United Soybean Board, released in Feb. 2010)
- 5. Updated gas-to-liquids (GTL), coal-to-liquids (CTL), biomass-to-liquids (BTL), and coal and biomass to liquids (C/BTL) pathways with additional design options and updated efficiency and co-product yields:
  - a. Updated plant design parameters for natural gas (NG), biomass, coal, and coal/biomass to Fischer-Tropsch (FT) diesels (Reference: Xie, X., J. Han, and

- M. Wang, 2010, “Life Cycle Assessment of FT Diesel from Coal and Biomass,” submitted to *Environmental Science & Technology*)
- b. Added energy-based allocation and market value-based allocation methods to the following pathways:
    - i. NG, biomass, or coal to methanol or dimethyl ether
    - ii. NG to FT naphtha
  6. Added new pathways for landfill gas (LFG) to produce compressed natural gas (CNG) and liquefied natural gas (LNG):
    - a. Added LFG-to-CNG and LNG pathways (Reference: Mintz, M., J. Han, M. Wang, and C. Saricks, 2010, “Well-to-Wheels Analysis of Landfill Gas-Based Pathways and Their Addition to the GREET Model,” ANL/ESD/10-3, Available at: <http://www.transportation.anl.gov/pdfs/TA/632.PDF>)
  7. Updated the fuel economy of gasoline baseline vehicles on the basis of the most recent EIA and U.S. EPA publications and updated fuel economies of other vehicle technologies on the basis of simulations using Argonne’s PSAT model:
    - a. EIA 2010 projections and EPA fuel economy trend report are used to calculate the fuel economies of baseline vehicles (Reference: Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2008, EPA Office of Transportation and Air Quality, EPA420-R-08-015, September 2008)
    - b. Estimates of future fuel economies for baseline gasoline vehicles are calculated on the basis of EIA’s Annual Energy Outlook 2010 projections of fuel economies for automobiles and light-duty trucks
    - c. Fuel economies for the following fuel/advanced vehicle technologies (hybrid electric vehicles [HEVs], PHEVs, and fuel-cell vehicles [FCVs]) relative to baseline gasoline vehicles are updated with PSAT simulation results: gasoline and diesel conventional internal combustion engine vehicles (ICEVs), HEVs and PHEVs; E85 ICEVs, HEVs, and PHEVs; and hydrogen ICEVs, HEVs, FCVs, and FC-PHEVs. Relative fuel economies for all other advanced fuel/vehicle technologies are consistent with the earlier version of GREET (GREET1.8c) and are drawn from broad literature data
  8. Updated projections of U.S., California (CA), and northeastern (NE) electricity generation mixes on the basis of EIA’s Annual Energy Outlook 2010:
    - a. Expanded renewable electricity generation to separately include solar, wind, hydro, and geothermal power generation technologies
    - b. Added forest residue-based power plant technology
    - c. Updated electricity generation mixes for 2010 and later years on the basis of the Annual Energy Outlook (AEO) 2010
  9. Added options to account for energy uses and emissions associated with the construction of the infrastructure of various electric power plants (Reference:

Sullivan, J.L., C.E. Clark, J. Han, and M. Wang, “Life Cycle Analysis of Geothermal Systems in Comparison to Other Power Systems,” forthcoming)

10. Updated PHEVs and BEVs pathways on the basis of revised electricity consumption in charge-depletion (CD) mode and the driving range of electric vehicles and included estimates for two different PHEV designs (power-split design and series design)  
(Reference: Elgowainy, A., J. Han, L. Poch, M. Wang, A. Vyas, M. Mahalik, and A. Rousseau, 2010, “Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-In Hybrid Electric Vehicles,” ANL/ESD/10-1, Available at: <http://www.transportation.anl.gov/pdfs/TA/629.PDF>)
  - a. PSAT simulations assumed power-split design for PHEV 10/20 and series design for PHEV 30/40
  - b. Used EPA fuel economy-based formulae to adjust fuel economy on the city and highway cycles to reflect (on-road) “real-world” driving conditions  
(Reference: “Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates,” EPA Office of Transportation and Air Quality, EPA420-R-06-017, December 2006)
  - c. Used a fuel economy adjustment factor of 0.7 (the ratio of on-road fuel economy to lab-tested fuel economy) to adjust electricity consumption on the city and highway cycles for series PHEVs and BEVs to reflect real-world driving conditions
  - d. Used a fuel economy adjustment factor of 0.7 to adjust the electric range on the city and highway cycles for series PHEVs and BEVs to reflect real-world electric range of these vehicles
  - e. Used a 43% city/57% highway weighting factor to generate composite fuel economy values for 2008 and later model year vehicles (Reference: “Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2008,” EPA Office of Transportation and Air Quality, EPA420-R-08-015, September 2008).
  - f. Used the utility factor (UF) to determine vehicle miles traveled (VMT) share for charge-depletion (CD) and charge-sustaining (CS) operations on the basis of the adjusted on-road electric range of PHEVs (i.e., in CD operation)
11. Updated and revised several transportation and distribution activities and parameters
  - a. Updated the transportation emission factors for medium- and heavy-duty diesel trucks, barges, locomotives, and ocean tankers to reflect EPA emission regulations for these technologies
  - b. Updated cargo payloads of ocean tanker for crude oil and other fuels